PROGRESS REPORT FOR DOE ARM (SCW0502)

TITLE: Examine Aerosol Indirect Effects with a 3-D Cloud Resolving Model and ARM Data: Develop and Validate Aerosol/Cloud Parameterizations for GCMs

PI: Catherine C. Chuang
Lawrence Livermore National Laboratory

GOAL

The goal of this proposal is to refine our aerosol/cloud parameterizations for use in climate models in order to place the estimate of aerosol indirect effects on a much more quantitative foundation than is available at present. Our approach is to (1) develop more realistic cloud drop parameterizations with detailed aerosol microphysics, (2) apply these parameterizations into a 3-D cloud resolving model and validate those aspects that depend on an accurate treatment of aerosol/cloud interactions with the ARM measurements, and (3) quantify aerosol climatic impacts using the tools developed for the Climate Change Prediction Program - ARM Parameterization Testbed (CAPT).

ABSTRACT

Aerosols directly affect the radiative fluxes by scattering/absorbing radiation. Further, aerosols may change cloud microphysical properties and indirectly affect the radiative fluxes. However, aerosol/cloud interactions remain one of the most uncertain aspects of climate models today. The goal of this proposal is to place the estimate of aerosol indirect effects on a much more quantitative foundation than is available at present.

We propose to extend our previous effort on the climatic impacts of aerosol/cloud interactions by developing the improved parameterizations that include detailed aerosol microphysics. We will compare the simulated aerosol properties from a global aerosol model to those measured at the ARM sites. The new parameterizations will be incorporated into a 3-D cloud resolving model to investigate the effects of aerosols on cloud/precipitation properties and the resulting radiation fields. We will explore the potential of ARM data to directly infer the indirect effects of aerosols. Furthermore, we will examine whether the autoconversion parameterizations that are currently used within GCMs are faithfully reproducing the behavior simulated in the cloud resolving model and whether data from ARM can be used to verify the response of the cloud resolving model.

Finally, we will use the tools developed for CAPT to test whether our aerosol/cloud parameterizations bring the simulated climate into closer agreement with the observed statistics over a wide range of frequencies. This would be the first attempt quantifying the aerosol indirect effects from such analysis. This validation is crucial to reduce uncertainties in GCM predictions of future climate.

PROPOSED WORKS FOR YEAR 1

* Compare IMPACT simulated aerosol concentrations and optical depths with ARM data from Raman lidar
* Develop new cloud drop parameterizations with detailed aerosol microphysics
* Modify LLNL cloud resolving model to accommodate aerosol/cloud interactions
* Test CAM3 with aerosol/cloud parameterizations developed in our previous studies

ACCOMPLISHMENT DURING THE FIRST SIX MONTHS

The focus of our first year is to extend our previous cloud drop parameterizations to include the effects of major aerosol processes. Virtually all properties of atmospheric aerosols and clouds depend strongly on aerosol microphysical properties. Moreover, molecular processing on aerosol surfaces alters the hygroscopic characteristics and composition of aerosols. These processes, together with other physical properties (i.e., size, density, and refractive index), determine the atmospheric lifetime of aerosols and their radiative forcing. To better represent the physical properties of aerosols, we adapted an aerosol microphysics model that simulates aerosol size distribution. Work toward this goal was done in collaboration with Professor Wexler of University of California at Davis. Professor Wexler's group has developed sectional models of atmospheric aerosol dynamics that include an arbitrary number of size sections and chemical compounds. The model, AIM (Aerosol Inorganics Model), is designed to predict the mass distribution and composition of urban and regional particulate matter (*Sun and Wexler*, 1998a, b). This model is currently incorporated into EPA's Models-3 air quality modeling platform/CMAQ (Community Multiscale Air Quality) to test its performance with previous simulations of CMAQ over the continental US.

We modified AIM into a box model and successfully implemented it into the aerosol version of LLNL global chemistry transport model (IMPACT T3A) (*Chuang et al*., 2002) to predict both the composition and size distributions of atmospheric aerosols (*Chuang and Chin*, 2005). In an Eulerian frame of reference, the distributions of particle size and composition are influenced by emission and deposition, condensation and evaporation, advection and diffusion, gravitational settling, and aerosol-phase chemical reactions. Nucleation and coagulation processes are currently not included in AIM, arguing that only a small fraction of aerosol mass is associated with homogeneous H_2SO_4-H_2O and H_2SO_4- HN_3-H_2O nucleation and coagulation is too slow to influence aerosol number distributions for particle diameters > 0.05 μm (*Zhang and Wexler*, 2002). While the growth of aerosols by condensation, in general, is being recognized as the leading process for modification of aerosol size distribution, homogeneous nucleation could be important in the upper troposphere where surface area of existing particles is relatively low (*Clarke*, 1993) or in regions recently scavenged by cloud (*Hoppel and Frick*, 1990) or in the proximity of clouds (*Hegg et al.*, 1990). We will revisit these issues to complete physical processes during the second half of the first year.

We performed a full year simulation of IMPACT T3A/AIM plus a 3-month spin up from clean atmosphere using MACCM3 meteorology at resolution of $4^o \times 5^o$ and 52 vertical layers. Model input includes emissions of primary aerosols of organic carbon (OC) and black carbon (BC) as well as aerosol precursors of SO_2, DMS, and H_2S from the Global Emissions Inventory Activity (GEIA) with both anthropogenic and natural origins. Emissions of sea salt and dust are calculated interactively in IMPACT as a function of local surface wind speed and other meteorological conditions (*Gong et al.*, 1997; *Ginoux et al.*, 2001). Figure 1 presents the simulated seasonal variations of aerosol compositions and size over the ARM sites at σ levels of 1 (~ surface) and 0.6 (z ~ 4 km), respectively. Results are shown for simulations with 8 size sections. Significant regional variabilities in aerosol size distributions and compositions are noted. The size distribution of atmospheric aerosols not only depends on the initial size distribution of primary aerosols but also depends on the growth and removal processes. The growth mechanism is mainly associated with condensation and evaporation of condensable (e.g. H_2SO_4) and volatile (e.g. HNO_3 and H_2O) gas species with a rate strongly dependent on the composition at mass transfer, while the removal processes include gravitational settling, as well as dry and wet scavenging. These processes together with the short life time of aerosols result in large temporal and spatial variations in aerosol size distribution and compositions.

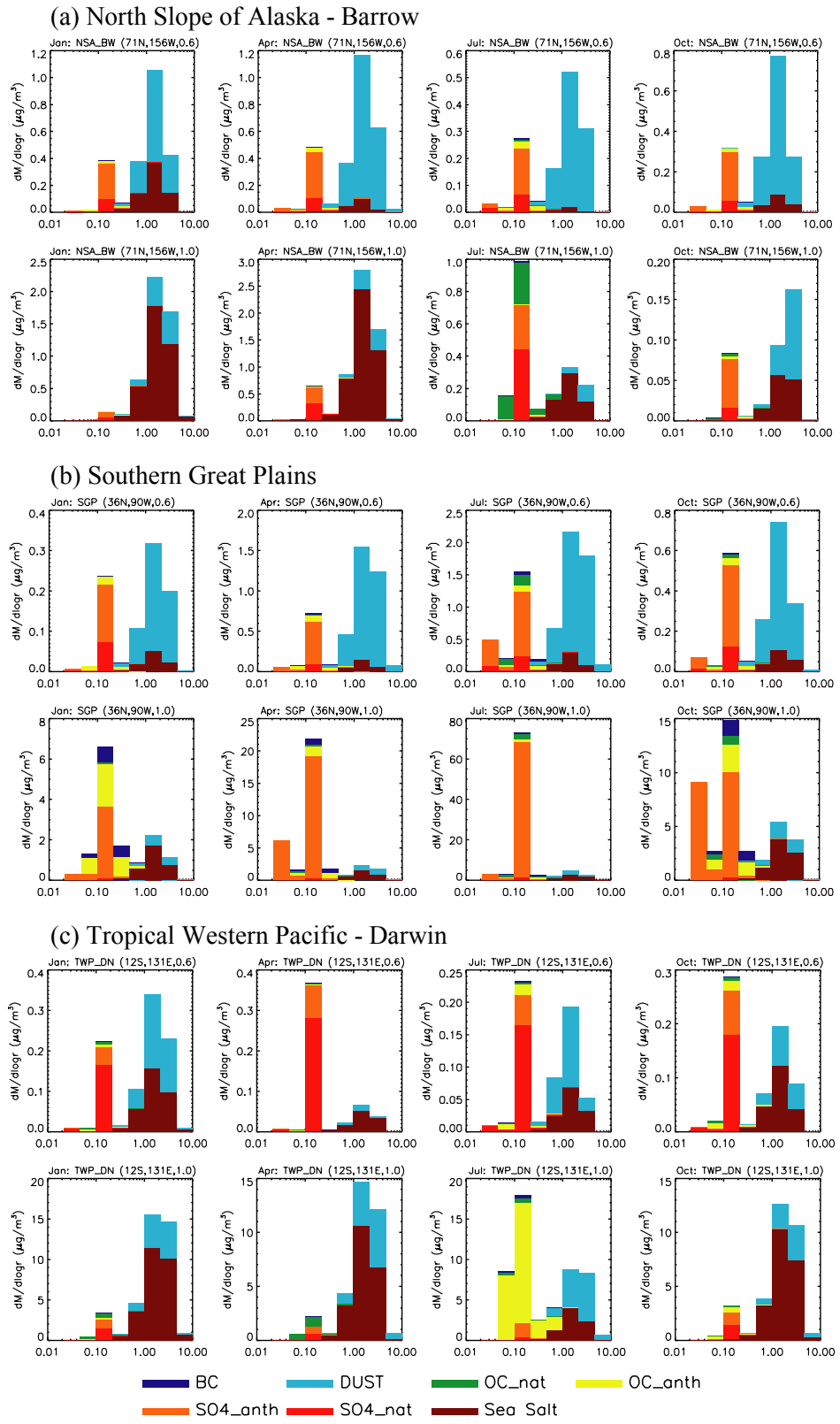
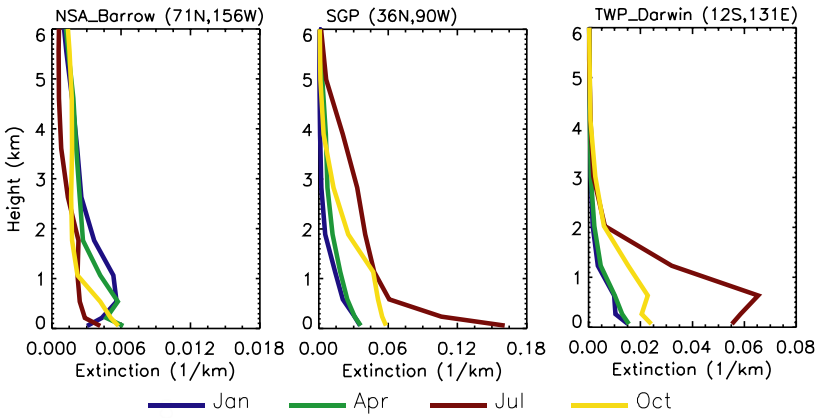


Figure 1. Simulated seasonal variations of aerosol compositions and size distributions ($\mu g/m^3$) over (a) NSA, (b) SGP, and (c) TWP at σ = 1.0 and 0.6. Contribution from individual species is denoted by the color legend.

We have examined the sensitivity of aerosol extinction vertical profiles to chemical composition over the ARM sites. Figure 2a presents the seasonal variations of total clear sky extinction by aerosols, and Figure 2b presents the annual average clear sky extinction by individual aerosol component. It is noted that sulfate is the dominant component for aerosol extinction over NSA and SGP, while organic carbon dominates over TWP. Both large values in summer over SGP and TWP are associated with anthropogenic emissions of fossil fuels and biomass burning from either local sources or long range transport. We are in the process to compare our simulations with available measurements at SGP. We plan to explore aerosol radiative impacts through scattering and absorbing solar radiation as well as through aerosol/cloud interactions.

(a) Seasonal variations of total aerosol extinction over clear sky



(b) Annual average extinction over clear sky by individual aerosol component

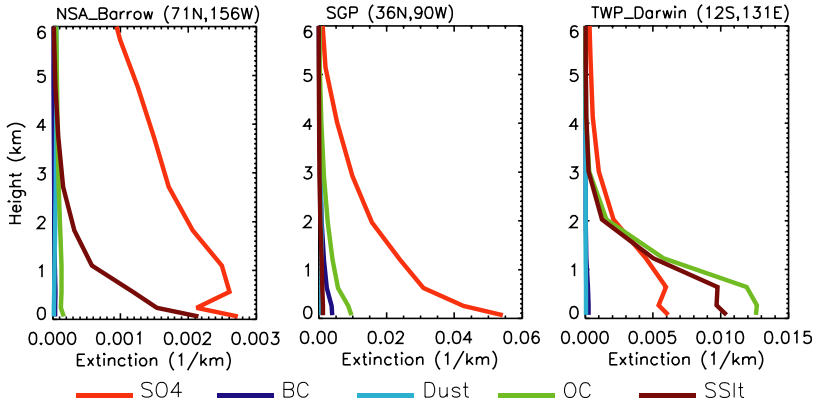


Figure 2. Vertical variations of simulated aerosol extinction.

FUTURE ACCOMPLISHMENTS

For the forthcoming period, we will compare the simulated aerosol properties from a global aerosol model to those measured at the ARM sites and develop an improved cloud drop parameterization that takes into account aerosol microphysical processes. The new parameterizations will be incorporated into LLNL 3-D cloud resolving model (*Chin and Wilhelmson*, 1998) to investigate the effects of aerosols on cloud/precipitation properties and the resulting radiation fields. Modification of our CRM to accommodate aerosol/cloud interactions is

underway. We will explore the potential of ARM data to directly infer the indirect effects of aerosols. Furthermore, we will examine whether the autoconversion parameterizations that are currently used within GCMs are faithfully reproducing the behavior simulated in the cloud resolving model and whether data from ARM can be used to verify the response of the cloud resolving model.

Finally, we will use the tools developed for CAPT (*Phillips et al.*, 2003) to test whether our aerosol/cloud parameterizations bring the simulated climate into closer agreement with the observed statistics over a wide range of frequencies. This would be the first attempt quantifying the aerosol indirect effects from such analysis. This validation is crucial to reduce uncertainties in GCM predictions of future climate.

REFERENCES

Chin, H.-N.S., and R.B. Wilhelmson, 1998: Evolution and structure of tropical squall line elements within a moderate CAPE and strong low-level jet environment, *J. Atmos. Sci.*, **55**, 3089-3113.

Chuang, C.C., D. Bergman, J. Dignon, and P. Connell, 2002: Final Report for LDRD Project "A New Era of Research in Aerosol/Cloud/Climate Interactions at LLNL", LDRD-UCRL-ID 146980. (http://www-r.llnl.gov/ibis/lof/documents/pdf/240899.pdf)

Chuang, C.C., and H-N S. Chin, 2005: Modeling the vertical profiles of aerosol characteristics and radiative impacts over the ARM sites, submitted to the *15th ARM Science Team Meeting*, March 14-18, 2005, Daytona Beach, Florida.

Clarke, A.D. 1993: Atmospheric nuclei in the pacific midtroposphere: Their nature, concentration, and evolution, *J. Geophys. Res.* **98**, 20633-20647.

Ginoux, P., M. Chin, I. Tegen, J.M. Prospero, B. Holben, O. Dubovik, and S.-J. Lin, 2001: Sources and distributions of dust aerosols simulated with the GOCART model, *J. Geophys. Res.*, **106**, 20,255-20,273.

Gong, S.L., L.A. Barrie, and J.P. Blanchet, 1997: Modeling sea-salt aerosols in the atmosphere. 1. Model development, *J. Geophys. Res.*, **102**, 3805-3818.

Hegg, D.A., Radke, L.F. and Hobbs, P.V. 1990: Particle production associated with marine clouds, *J. Geophys. Res.* **95**, 13917-13926.

Hoppel, W.A. and Frick, G.M. 1990: Submicron aerosol size distributions measured over the tropical and south Pacific, *Atmos. Environ.* **24A**, 645-659.

Phillips, T.J., G.L. Potter, D.L. Williamson, R.T. Cederwall, J.S. Boyle, M. Fiorino, J.J. Hnilo, J. G. Olson, S. Xie, and J.J. Yio, 2003: The CCPP-ARM Parameterization Testbed (CAPT): Where Climate Simulation Meets Weather Prediction. PCMDI Report 70, 27pp, available from: http://www-pcmdi.llnl.gov/publications/pdf/rpt70.pdf

Sun, Q., and A.S. Wexler, 1998a: Modeling urban and regional aerosols - Condensation and evaporation near acid neutrality, *Atmos. Environ.*, **32**, 3527-3531.

Sun, Q., and A.S. Wexler, 1998b: Modeling urban and regional aerosols near acid neutrality - application to the June 24-25 SCAQS episode, *Atmos. Environ.*, **32**, 3533-3545.

Zhang, K.M., and A.S. Wexler, 2002: Modeling the number distributions of urban and regional aerosols: Theoretical foundations, *Atmos. Environ.*, **36**, 1863-1874.